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SECTION 3: ENTRAINMENT AND IMPINGEMENT IMPACTS

Introduction

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Two major areas of concern are discussed in section 3: (1) the extent of the direct impact on fish populations resulting from entrainment and impingement at Hudson River power plants; and (2) the effect of biological compensation on the ability to predict the long-term consequences of entrainment and impingement on fish populations. The final paper in this section considers the contribution of striped bass spawned in the Hudson River to the Atlantic stock, and it serves as a framework for extending entrainment and impingement impacts on Hudson River striped bass to the Atlantic stock. Power plant impact (or just impact) refers to the effect of power plant operations on year classes or populations, as distinct from the effect on individual organisms, which is referred to as mortality.

Both physical and biological data are needed to obtain direct entrainment and impingement impact estimates for year classes (Figure 44). Estimates of direct impact may then be combined with a life-cycle model to obtain long-term impact estimates. In addition to age-specific life history data, the life-cycle model requires the incorporation of biological compensation to more realistically assess long-term impacts on fish populations. Compensation in the present context refers to changes in life history parameters (e.g., reproduction and survival) that tend to dampen population effects of additional mortality on any life stage of fish. The following definitions of the early life stages of fish were used consistently during the Hudson River power plant case: (1) egg, or the embryonic life stage commencing with fertilization and lasting until hatching; (2) yolk-sac larva, or the transitional life stage from hatching through development of a complete and functional digestive system; (3) post–yolk-sac larva, or the life stage from initial development of a complete and functional digestive system (regardless of degree of yolk or oil retention) to transformation to the juvenile life stage; and (4) juvenile (also referred to as young of year), or the life stage beginning when the individual acquires the full complement of adult fin rays and extending to age I (i.e., through 31 December of the year in which a fish was spawned). Yearling (age I) and older (age II+) fish are generally considered to be adults.

Entrainment is the process by which small fish (e.g., fish eggs and larvae, usually less than 50 mm long) are drawn into the cooling water intakes of power plants and pass through the meshes of the debris screens. Estimates of the numbers of fish eggs and larvae entrained require such physical data as plant flows and river morphometry and such biological data as far-field distributions and life stage durations (see papers in Section 2 of this monograph). Two other factors are important in determining how many fish eggs and larvae are killed as a result of power plant entrainment. The *W*-factor, or ratio of egg or larva density in the power plant intake to that in the river nearby, is included in entrainment models primarily to account for the effects of nonuniform distribution of organisms in the river on the number entrained (Boreman et al. 1982). Organisms may concentrate in shallow nearshore water from where the cooling water may be primarily withdrawn, which produces a *W*-factor greater than 1; *W*-factors less than 1 may also occur. The entrainment mortality factor, denoted as either the *f*-factor or simply as *f*, is the fraction of entrained live organisms killed as a result of passage through the plant. Physical, thermal, and chemical stresses encountered by entrained organisms as they pass through the power plant cooling system can cause mortality. Additional mortality may occur in the thermal plume created by the heated discharge as it enters the river. Muessig et al. discuss the *f*-factor in this section.

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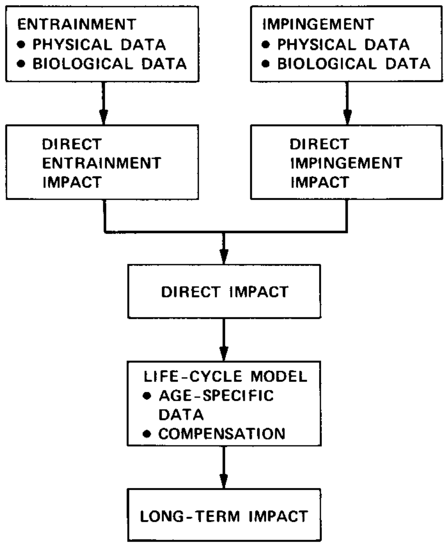

FIGURE 44.—Conceptual framework for the analysis of population-level impacts due to entrainment and impingement of fish at power plants (modified from Figure 2 in Christensen et al. 1981).

Due to competing sources of mortality (e.g., natural mortality) during the entrainment process, an approach suggested from classical fisheries science (Ricker 1975) is used to obtain estimates of direct entrainment impact. This approach is based on conditional mortality rates, or the fraction of an initial population that would be killed by some agent during the year if no other sources of mortality operated. Conditional entrainment mortality rates are used as estimates of the direct impact of power plants on individual year classes. In this section, Christensen and Englert discuss the historical development of entrainment models for Hudson River striped bass. Englert and Boreman compare two approaches for estimating conditional entrainment mortality rates and investigate the evolution of input parameters with changes in estimated conditional entrainment mortality rates. Boreman and Goodyear use a data-intensive methodology to estimate conditional entrainment mortality rates for fish populations entrained at Hudson River power plants.

Impingement refers to the entrapment of larger organisms (e.g., juveniles and adult fish longer than 50 mm) on the surface of power plant debris screens. An assessment of impingement impact on fish populations requires plant flow information (Hutchison 1988, this volume), in addition to estimates of impingement rates (Mattson et al., this section) and of impingement survival (Muessig et al.). Barnthouse and Van Winkle employ an empirical model for obtaining estimates of the conditional impingement mortality rates.

Conditional power plant mortality rates from entrainment or impingement are independent of conditional natural and fishing mortality rates, which represent the fraction of each year class lost to natural causes or to fishing. Impacts on fish populations, expressed as conditional mortality rates, are particularly useful for three major reasons. (1) They can be compared and combined with other conditional mortality rates such as those estimated for other plants, other life stages, or other types of environmental stress. (2) Conditional mortality rates can be entered directly into life-cycle models for assessing potential long-term impacts on fish populations. (3) Provided that density-dependent mortality is low relative to density-independent mortality, conditional entrainment and impingement mortality rates are approximately equal to the fractional reductions in year-class abundance due to entrainment and impingement. Barnthouse et al. (1984) noted that the direct impact assessment approach became extremely useful during the settlement negotiations, when the primary concern was with the relative effectiveness of alternative schemes for reducing impacts due to entrainment and impingement. Englert et al. (1988, this volume) describe how conditional entrainment mortality rates were used to schedule reductions in withdrawal of cooling water and maintenance shutdowns of power plant units for minimizing entrainment impacts.

Conditional entrainment and impingement mortality rates also may be extrapolated to obtain estimates of long-term impacts. In addition to life-table data, an appropriate estimate of biological compensation is necessary for making meaningful long-term projections. Biological compensation represents the ability of a fish population to offset, either in whole or in part, reductions in numbers caused by an increase in mortality (e.g., as a result of entrainment and impingement). Compensation results from density-dependent processes; that is, processes, such as reproduction or survival, that control the size of a population as a function of density of that population. Goodyear (1980) described several density-dependent processes (both compensatory and depensatory) found in fish populations. In general, compensatory processes have a stabilizing effect on a population because they tend to increase mortality or decrease reproduction as population size increases. Depensatory processes are destabilizing for a population because they tend to increase mortality or decrease reproduction as population size decreases.

A search for evidence of compensation in Hudson River fish populations formed part of the rationale for collecting life history data for selected fish populations, as described in Section 2. Major emphasis of the search for compensatory processes dealt with striped bass, white perch, and Atlantic tomcod through the study of age structure, age of maturity, fecundity, growth, condition, and mortality. The search emphasized early life history stages (i.e., eggs, yolk-sac larvae, and post–yolk-sac larvae) during which compensatory processes were thought most likely to occur. Sissenwine et al. (1984) identified two mechanisms (cannibalism and competition for limited resources) that form the biological rationale for expecting compensation. However, the limited number of years for which data were collected and the high variability in parameter estimates obtained resulted in an inability to quantify the compensatory process under investigation.

Stock–recruitment models, which describe the numerical relationship between stock size and subsequent recruits into the stock, were developed by fisheries scientists (Ricker 1954, 1975; Beverton and Holt 1957) and are used to represent compensatory processes in fish populations. In this section, Savidge et al., Lawler, Christensen and Goodyear, and Fletcher and Deriso discuss the usefulness of stock-recruitment models as applied to fish populations in the Hudson River estuary. Because of the controversial nature of these papers on compensation, their authors were offered a chance to rebut one another, and the comments submitted are included in this section. Goodyear discusses the management implications of using stock–recruitment models in particular, and of assuming compensatory processes in general.

Finally, Van Winkle et al. treat the contribution of Hudson River striped bass to the Atlantic stock, based on an intensive 1-year sampling effort in 1975 by Texas Instruments Incorporated. This paper provides a framework for extending the effect of entrainment and impingement impacts by Hudson River power plants to the Atlantic coastal stock.

Christensen et al. (1981) discussed the convergence and divergence of opinion through time regarding the various aspects of power plant impacts on Hudson River fish populations. The papers that follow reflect both the convergence and divergence of methods, results, and conclusions over the years prior to the settlement.

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